Producing Energy and Soil Amendment from Dairy Manure and Cotton Gin Waste

M. A. Macias-Corral, Z. A. Samani, A. T. Hanson, R. DelaVega, P . A. Funk

Abstract. *Millions of tonnes of feedlot manure and cotton gin waste are generated in the U.S. each year. Dairy and feedlot operations in New Mexico produce 1.2 million tonnes of manure annually. Traditionally, manure has been used as a soil amendment in agriculture. However, land application of manure is limited in New Mexico due to problems with salinity, potential groundwater contamination, and limited availability of agricultural land. Waste treatment alternatives are sought. A two-phase anaerobic digestion system was used to evaluate the feasibility of producing methane and soil amendment from mixed agricultural wastes. Cotton gin waste and dairy manure were combined and used as feedstock. Under mesophilic conditions, 48% of the combined waste was converted into biogas. The gas yield was 87 m^3 of methane per tonne of mixed waste. Methane concentration in the biogas averaged 72%. Gas production with mixed waste increased 35% compared to digesting dairy waste alone. Nutrient analyses of the residuals showed that they could be used as soil amendments. Residual solid material from the two-phase anaerobic digester had a considerably higher nitrogen and lower sodium content than aerobically composted manure. Anaerobic digestion lasted from one to three months and required 0.15 m^3 of water per 1 m^3 of waste. Aerobic composting of similar waste in New Mexico takes eight to nine months and consumes 1.2 m^3 of water per 1 m^3 of waste.*

Keywords. *Anaerobic digestion, Animal waste, Cotton gin waste, Energy, Environment, Soil amendment.*

The livestock industry in the U.S. is an important source of income as well as environmental concern. The amount of animal manure produced in the U.S. is 130 times greater than the amount of human waste (USDA, 2002; U.S. Senate Committee on Agriculture, Nutrition, and Forestry, 1997). The 2002 Farm Bill identified manure as a major environmental problem. The potential pollutants from decomposing livestock manure include biological oxygen demand (BOD), pathogens, nutrients, and methane and ammonia emissions. These pollutants result in contamination of soil, surface water, groundwater, and air. There is also concern about the impact of uncontrolled methane emissions on global warming.

The New Mexico dairy industry generates 1.2 million tonnes of manure each year. It also is the highest income producing agricultural industry in the state (Dairy Producers of New Mexico, 2000). Traditionally, manure has been used in agriculture as a soil amendment, either through direct application or after aerobic composting. However, land application of waste in New Mexico is limited due to the high salt content of the solid waste, limited water supply and agricultural land area, and low rainfall. Farmers are generally reluctant to use manure in their fields due to the high cost of manure handling and salinity problems associated with manure application. Furthermore, the recent Unified National Strategy for Animal Feeding Operations (EPA, 2003) would require concentrated animal feeding operations (CAFO), which are those with 750 dairy cows or 1000 cattle, to develop a comprehensive nutrient management plan for field application of waste. Consequently, manure management systems that can prevent pollution and produce energy are becoming increasingly attractive.

Another major agricultural waste in the U.S. is that generated by the cotton ginning industry. Approximately 2.8 million tonnes of cotton gin waste (CGW) are produced each year across the Cotton Belt of the U.S. (Thomasson et al., 1998). A 1990 regulatory change made the incineration of CGW illegal. More than a decade later, there is still an urgent need for alternative disposal methods. Over the years, extensive research has been performed to evaluate the feasibility of using CGW for various applications. These include manufacturing fire logs (Karpiscak et al., 1982), pellet stove fuel (Holt et al., 2004), direct use as an energy source (Beck and Clemens, 1982; Lacewell et al., 1982; White et al., 1996), use as livestock feed (Holloway et al., 1974; Poore and Rogers, 1995; Castleberry and Elam, 1998), raw material in asphalt roofing (Truhett, 1994), and direct use as a soil amendment. Despite extensive research efforts, few uses of CGW have reached widespread commercial acceptance, and CGW remains a financial liability for most producers (Castleberry and Emmett, 1999). CGW also consumes space at the gins and is a potential fire hazard.

Anaerobic digestion (AD) of cotton gin waste is an alternative. However, it is difficult to carry out due to the low nutrient value of CGW and the complexity associated with

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digestion of high-cellulose cotton fiber. On the other hand, manure has a high nitrogen value compared to CGW. In addition, bovine manure has celluloytic bacteria that can break down the cellulose present in CGW. Combining the two feedstocks could potentially result into a biofuel source.

This article demonstrates the application of a pilot-scale two-phase bio-fermentation technology as an alternative for agricultural waste management, producing energy and soil amendment. The feedstocks were dairy manure and cotton gin waste.

Materials and Methods

Anaerobic Digestion Process

Anaerobic digestion is a process where a complex organic substrate can be broken down by a microbial consortium in an oxygen-free environment. In the AD process, acid-forming bacteria convert complex organic matter into volatile fatty acids (VFA). A second population of organisms (methanogens) converts the VFA into biogas. In a traditional single-phase digester, both types of bacteria coexist in the same environment. However, VFA production proceeds at a much faster rate than methanogenesis, resulting in VFA accumulation, pH drop, and consequent inhibition of methanogens. An alternative two-phase anaerobic digestion method that separates the acid phase from the methane phase was recommended by Ghosh (1982). Separating the two phases facilitates optimizing the process. The project described here presents an improvement to Ghosh's method. By using the methane phase for rapid inoculation and startup of the solid phase, the AD process was accelerated and operation was simplified.

Pilot-Scale Two-Phase Anaerobic Digestion System

The pilot-scale two-phase system constructed at New Mexico State University was made up of two different reactors: a solid phase reactor and two up-flow anaerobic filter (UAF) reactors, as shown in figure 1. The solid phase reactor consisted of a metal container with a capacity of 8 m^3. The UAF reactors were composed of two PVC pipe columns with a capacity of 0.4 m^3 each. The UAF reactors (column I and column II) were filled with inert commercial plastic packing material and seeded with methanogens. In the solid phase, water was added to the top of the waste using a sprinkler irrigation system. Leachate was collected at the bottom of the reactor using a sub-drain and recirculated through the solid bed until a desired pH level (5.5 to 6.0) was achieved. A low pH indicated sufficient accumulation of VFA in the leachate. Once the pH reached the desired level, the leachate was transferred to the UAF reactors where the VFA were converted to biogas. The UAF reactors' overflow was returned to the solid phase and the cycle was repeated.

This two-phase system had several advantages over a traditional single-phase reactor. First, the two-phase system used considerably less water compared to a single-phase system, thus reducing both digester and residual volume, and potentially reducing construction and transportation costs. In addition, the methane concentration in the biogas was generally higher (60% to 85%) compared to traditional single-phase systems, which generally yield a methane concentration of 40% to 60% (Yu et al., 2002).

Experimental Setup and Operation

Manure-Cotton Gin Mixed Waste

The solid phase was filled with a mixture of 618 kg of dairy manure and 521 kg of cotton gin waste (CGW), resulting in a dry weight ratio of 1:5. The manure used in this experiment was collected from the manure separator at a local dairy in southern New Mexico. Manure and CGW were placed in the solid phase in alternating layers of approximately 140 kg each. A series of prior laboratory batch experiments had demonstrated that a 1:5 ratio of manure to cotton gin waste resulted in the shortest digestion period. The solid phase was then sealed using a 1 mm (40 mil) polyethylene liner to provide an oxygen-free environment. Water equivalent to 15% of the total volume of solid waste was added to the solid phase. The leachate was recirculated through the solid phase every 6 h. The recirculation cycle was set considering the time (about 3 h) the leachate needed to pass through the solid bed. After 24 h, the pH of the leachate was reduced from an initial 7.6 to 5.8, at which point transfer to the UAF reactors started. This transfer was based on a plug flow approach. The residence time of the leachate in the UAF reactors ranged from one to three days, depending on the VFA concentration in the leachate.

The pH level in the solid phase leachate dropped from 5.8 to 5.4 initially and then progressively increased to 7.3 as the biodegradable organic matter in the solid phase was consumed. Leachate transfer to the UAF reactors continued until the pH level in the leachate reached 7.0, indicating a very low concentration of VFA. As leachate pH increased, methane production was gradually transferred from the UAF reactors to the solid phase. This was due to the transport of methanogens present in the recirculating leachate. Thus, the UAF reactors were used to accelerate methane production at the beginning of the process.

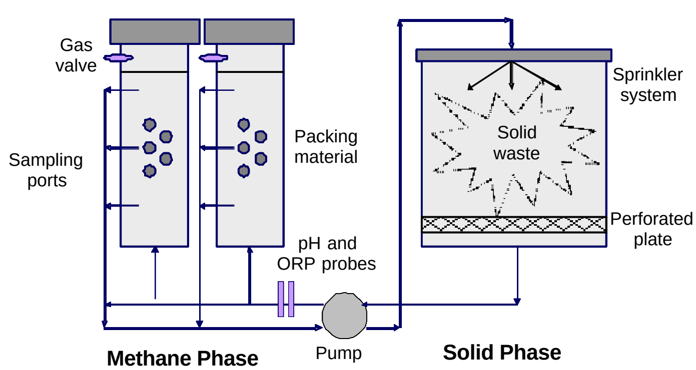

Figure 1. Pilot-scale two-phase anaerobic digestion system.

Manure

In a separate experiment, the solid phase was loaded with dairy manure as the only feedstock and the experiment was repeated. The gas production rate and other related parameters were measured in order to evaluate the potential gas production from a mixture of manure and CGW as compared to manure alone.

Analyses of Parameters

Temperature, pH, gas production rate, chemical oxygen demand (COD), and oxidation-reduction potential (ORP) were measured during the experiment to monitor the reactors' performance. Leachate samples were collected daily from the solid phase and the UAF reactors. Temperature and pH in the leachate were measured immediately after collection using a portable thermometer and a pH meter equipped with a temperature-compensating probe. In addition, the pH and ORP were monitored using in-line electrodes (Cole-Parmer) installed in the leachate transfer lines. Additional liquid samples of solid phase and UAF effluents were taken twice per week. These samples were analyzed for COD and VFA concentrations. COD was measured using a spectrophotometer (DR/2000, Hach Co., Loveland, Colo.). VFA were measured using standard distillation methods (APHA/AWWA/WEF, 1989).

The gas production rate was measured using a wet-tip gas meter. Gas samples were collected twice per week. The gas methane content was measured using a gas chromatograph (Tractor). Other gas components were not regularly measured during this experiment. However, periodic measurements (Yu et al., 2002) showed a carbon dioxide concentration of about 26% and other trace gases (nitrogen, hydrogen sulfide, and oxygen) lower than 3%.

Results and Analysis

The experiment with combined dairy manure and cotton gin waste as feedstock lasted for a total of 141 days. However, the majority of biogas production (80%) occurred during the first 45 days, as shown in figure 2. The two UAF reactors produced a total of 21.7 m^3 of biogas with an average methane concentration of 79% by volume. On the other hand, the solid phase produced 62.7 m^3 of biogas during the first 45 days of operation. The average methane concentration in the solid phase during this period started at 35% and quickly reached 65%. As time passed, gas production was transferred from the UAF reactors to the solid phase. This was due to the transfer and colonization of methanogens from the UAF to the solid phase. This rapid colonization by methanogens converted the solid phase into a methane-producing reactor without the need for further mixing or leachate transfer.

Figure 3 shows the methane concentration in the biogas from the UAF and solid phase reactors. The methane concentration ranged from 73% to 86% in the UAF reactors and from 35% to 74% in the solid phase. At the conclusion of the experiment, average biogas methane concentrations were 79% and 62%, respectively. The standard temperature and pressure (STP) methane production was 87 m^3 $tonne^{-1}$ of combined waste and 72 m^3 $tonne^{-1}$ of manure. Reported methane production rates from bovine manure range from 112 to 299 m^3 $tonne^{-1}$ (Texas A&M University, 2004). Manure methane yields depend on various factors including age, storage conditions, solids content, cattle feed characteristics, digestion period, type of reactor, and operational conditions. Reported organic waste to gas conversion rates range from 50% to 70% (Texas A&M University, 2004). In practical terms, when the volume of the digester is an important economic factor, mixed waste can produce 10.6 m^3 of STP methane per cubic meter of digester, while manure alone produces 6.9 m^3 of STP methane per cubic meter of digester. This represents a 35% improvement in biogas production when the two agricultural wastes are combined.

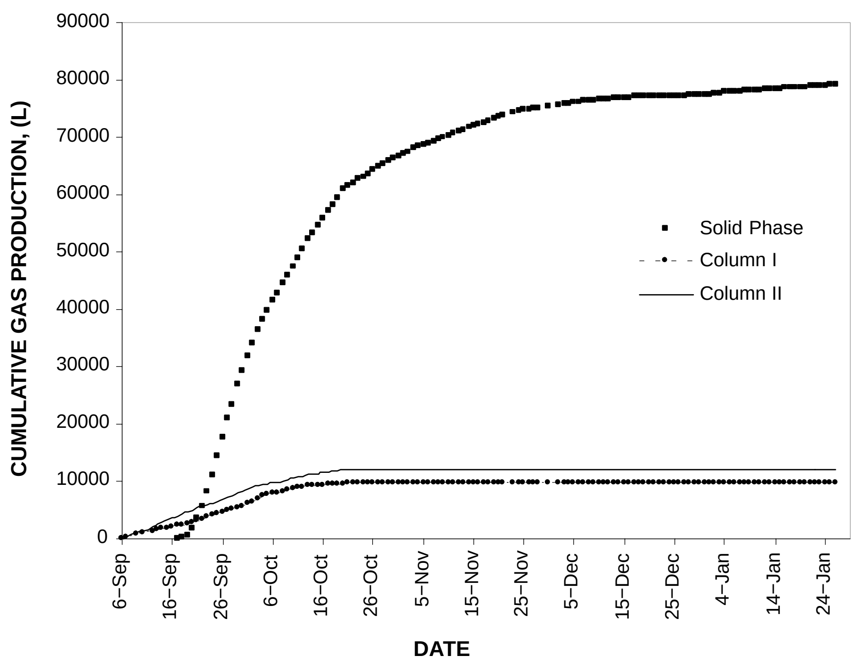

Figure 2. Cumulative gas production in the solid phase and UAF reactors.

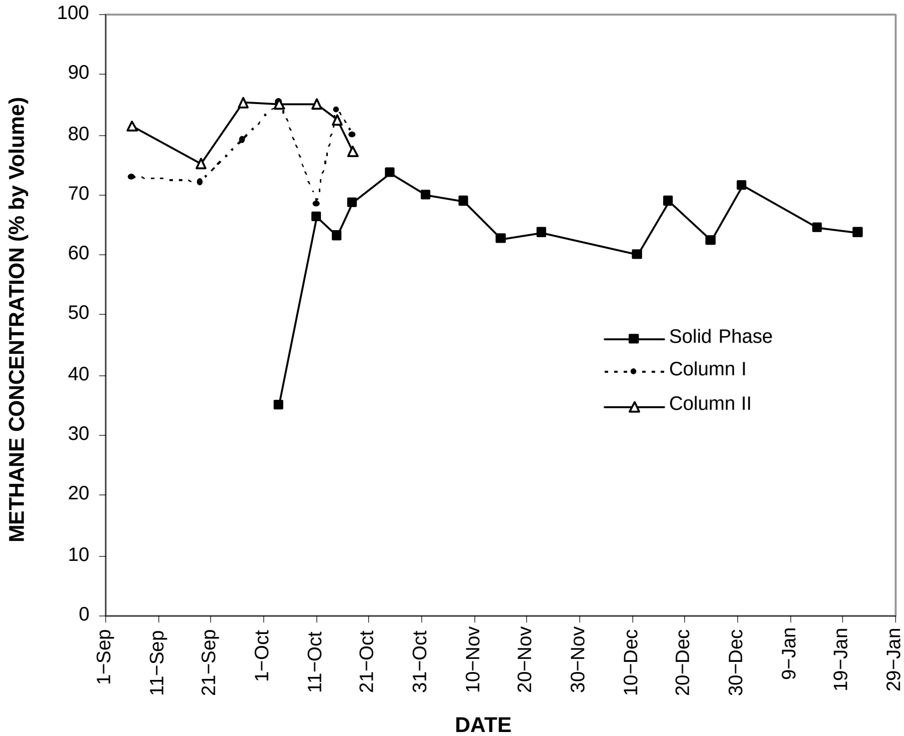

Figure 3. Methane concentration by volume in the gas produced in the solid phase and UAF reactors.

Figure 4 shows the concentration of COD in the solid phase and UAF liquid effluents. The COD concentration in the solid phase leachate reached a peak of 38,000 mg L^{-1} soon after the start of the experiment. After 45 days of operation, it declined to about 5,000 mg L^{-1}. This follows the same trend as the gas production rate, which started to decline after the same length of time. The VFA concentration in the UAF effluent was high during the first 10 days. This can be explained by the dormant status of methanogens in the UAF reactors, which were not fed for about six months prior to the initiation of the experiment. After 45 days, leachate transfer to the UAF reactors was terminated due to the negligible VFA concentration (<600 mg L^{-1}) in the solid phase leachate (fig. 5).

In order to quantify each constituent's contribution to methane gas production, a separate experiment was conducted with manure alone. Table 1 compares the methane production rate from combined mixed waste and manure. At the conclusion of each experiment, the leachate was drained and the solid phase cover was removed. Solid samples were collected and analyzed for moisture content. The difference in volume was calculated by comparing the initial and final depth of the material in the solid phase reactor. The wet weight of the residual was measured and its dry weight was

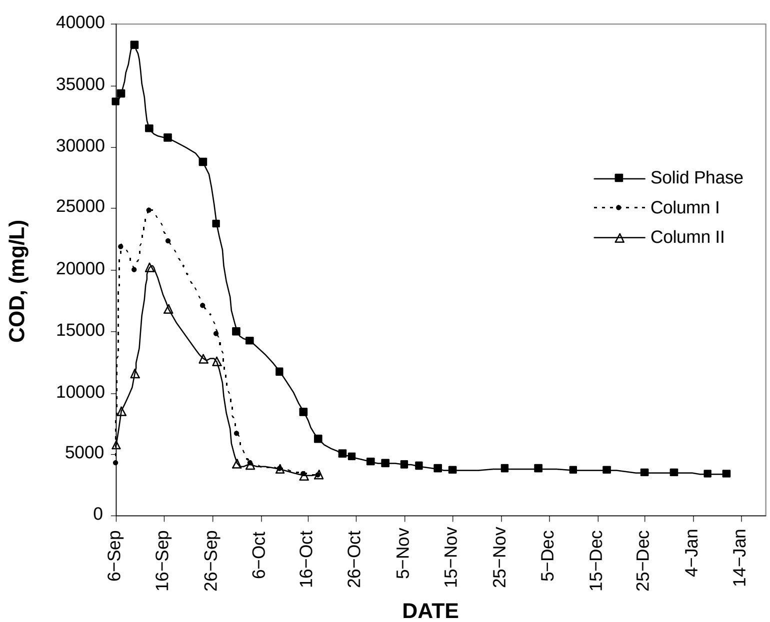

Figure 4. COD concentration in the effluents from the solid phase and the UAF reactors.

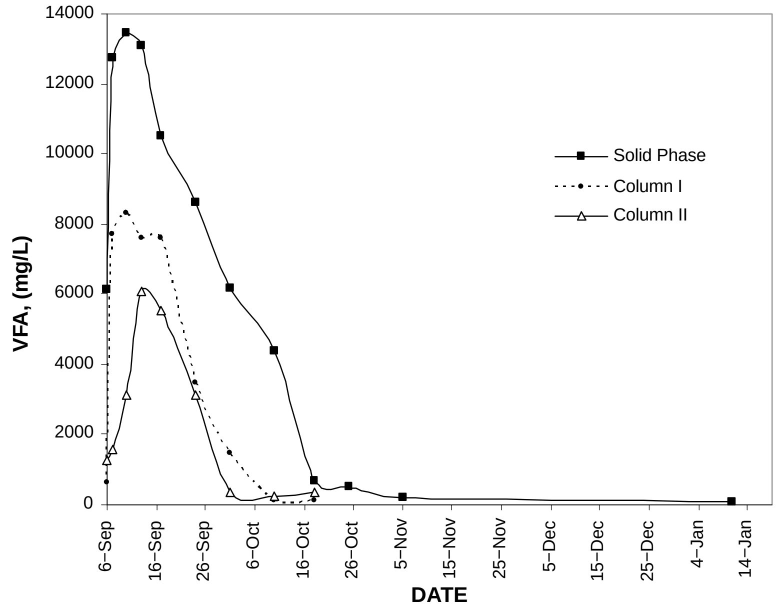

Figure 5. VFA concentration in the effluents from the solid phase and UAF reactors.

Table 1. Methane production and solids reduction in the experiments with combined manure - cotton gin waste (CGW) and manure.

Parameter	Combined Manure and Cotton Gin Waste	Manure
Dry weight before digestion (kg)	632	135
Bulk density (kg m^{-3})	121.5	96.4
Dry weight after digestion (kg)	304	76.4
Weight reduction (%)	48	43
Volume before digestion (m^3)	5.2	1.4
Volume after digestion (m^3)	2.2	0.9
Volume reduction (%)	58	36
Methane production (m^3 $tonne^{-1}$)	87	72

calculated by subtracting moisture content. In the combined waste experiment, there was a 58% reduction in volume and a 48% reduction in weight. In the manure experiment, the volume reduction was 36% and the weight reduction was 43%.

Table 2 compares the nutrient composition of the residuals from the anaerobic digestion of manure, combined manure and CGW, and aerobically composted manure from a local wholesale nursery. The results showed that the residual from anaerobic digestion could be used as a soil amendment. The residual from digested manure and combined waste had considerably higher nitrogen content than the aerobically composted manure. The low nitrogen content of aerobically composted manure can be attributed to nitrogen lost during the composting process through volatilization and leaching. In addition, the anaerobically digested residual had a lower sodium content than that of aerobically composted manure. This can be explained by the presence of salt in the water added to the aerobic composting piles.

Conclusions

This research showed that by using a two-phase digester, cotton gin waste combined with dairy manure could be

Table 2. Residual properties of anaerobically digested manure, combined waste, and aerobically composted manure.

Parameter	Anaerobically Digested Manure	Combined Manure and Cotton Gin Waste	Aerobically Composted Manure
Total N (%)	2.32	2.56	0.90
Total P (%)	0.15	0.43	0.20
Total K (%)	0.42	2.20	2.70
Sodium (%)	0.24	0.17	0.40

converted into biogas in a relatively short time, using a small amount of water (15% by volume). The proposed method used the rapid inoculation technique to seed the solid waste with pre-cultured methanogens. The process took advantage of the nutrients and celluloytic bacteria present in bovine manure to digest the carbon present in cotton gin waste. This anaerobic digestion system converted the solid organic waste into biogas and soil amendment. The average methane concentration in the biogas was 72%. The methane production rate was 87 m^3 of STP methane per tonne of combined waste and 72 m^3 of STP methane per tonne of manure alone. Cotton gin waste is a seasonal waste, while manure is continuously available. Combining the two agricultural wastes resulted in 35% more methane per cubic meter of solid phase. This fact represents a potential economic advantage. The nutrient analysis of the anaerobically digested residual showed that it can be used as a soil amendment. The anaerobic residuals had considerably more nitrogen and less sodium than aerobically composted manure. The lower nitrogen level in the compost was due to the loss of nitrogen through ammonia volatilization caused by high temperatures and frequent mixing. The higher sodium level could be explained by the addition of water containing salts.

Acknowledgements

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